IOP Conf. Series: Materials Science and Engineering **966** (2020) 012093 doi:10.1088/1757-899X/966/1/012093

Advanced standard operating procedures for survey of buildings and structures of metallurgical production

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Abstract. This article presents modern methods for determination of the depth of various types of foundations at the metallurgical industry facilities. It was decided to use modern geophysical research methods, such as seismic exploration methods in order to solve the tasks for determination of depth of pile foundations and deep foundations under conditions of operating production metallurgical site. Geometric parameters of foundations can be measured using engineering seismic equipment, and three-component measurement data shall be processed by means of specific processing flow. The use of coherency procedures makes it possible to separate the dedicated phases of reflection from the foundation bottom in the wave pattern. Reproducibility of results of foundation bottom laying depth with actual depth was checked using engineering seismic recording systems by uncovering of foundation check pit-holes at the blast furnace complex facilities No. 7 of JSC EVRAZ NTMK. The measurement accuracy of pile foundations and spread foundations equal to 0.5 meters was achieved by means of seismic techniques as a result of the measurements conducted at the metallurgical production facilities.

1. Introduction

As it is known, partial uncovering of foundation is required for surveying of the existing foundation of buildings and structures. Pit-holes are arranged in the proximity of foundation for this purpose. A pit-hole is prepared with such a section that normal conditions are provided for its trenching to the required depth, as well as conditions are provided for its inspection. The length of exposed site of foundation must be sufficient for determination of type and state estimation of its structure.

According to the Russian state standard GOST 31937–2011 [1], check pit-holes are dug depending on local conditions from the outside or inside of the foundations. The pit-holes are located basing on the following requirements:

– one pit is dug for each type of structure in each section of the foundation in the most loaded and unloaded locations;

– if there are mirrored or repeated (in plain view and along the outlines) sections, all the pit-holes are dug in one section, and one or two pit-holes are dug in other sections in the most loaded locations;

– in places where it is planned to install additional intermediate supports, one pit-hole is dug in each section;

– in addition, two or three pit-holes are dug for each building in the most loaded locations against the face of the wall where there is an output.

– in case of deformations of walls and foundations, it is obligatory to dig the pit-holes in these places and the additional pit-holes must be established in the process of operation in order to determine boundaries of soft soils of bases or boundaries of foundations, that are in unsatisfactory condition.

– the depth of the pit-holes located in the vicinity of the foundations must exceed the bottom laying depth by 0.5–1 m.

However, usually it is not possible to achieve normal conditions for inspection in case of significant groundwater inflow. A surface drainage from a pit-hole is allowed only for a very short time. Otherwise the soil particles will be removed from under the bottom of the foundations together with water, that can lead to their differential settlement. Therefore the pit-hole shall be dug down to the planned depth immediately prior to inspection of the foundation by the specialist.

It is very difficult to meet all necessary requirements of GOST 31937 [1] due to a large amount of utility lines, compliance with the industrial safety requirements as well as continuous production process under the conditions of production metallurgical site. Another factor, complicating the process of examination of the foundations of production metallurgical facilities (blast furnace complex facilities, bin trestle, etc.) involves their large depth of foundation which is 6–8 m from the ground level. Uncovering and backfilling of the pit-hole of such foundation, especially water-flooded one, is a labor intensive and important process.

The pile foundations, the depth of which cannot be measured by the method of pit sampling, shall be separately noted. In the open pit-hole of such foundation, it is possible to determine the mattress as well as pile arrangement and diameter, but the pile depth will remain unknown, although it can reach 25 m.

Finally, in the process of renovating metallurgical production facilities, there is a need to specify the depth of all foundations of the facility instead of selective amount in open pit-holes, which cannot be performed at the production site.

It was decided to use modern geophysical research methods, such as seismic exploration methods [2–5] in order to solve the tasks for determination of depth of pile foundations and deep foundations under conditions of operating production metallurgical site.

2. Equipment and measurement procedure

For determination of the geometric parameters of substructure of the foundations at the metallurgical production facilities, in particular, at the blast furnace foundations No. 6 and 7 (JSC ‘EVRAZ Nizhniy Tagil Iron and Steel Works’), equipment of seismic geophysical survey has been used successfully. TELSS-3 telemetric seismic recording system (LLC ‘GEOSIGNAL’, Moscow) and SGD-SEL engineering seismic recording station (LLC ‘SibGeofizPribor’, Novosibirsk) were used for surveying. GS-3C three-component seismic receivers (Geospace Technologies Eurasia, Ufa) served as seismic signal receivers. Both sets of equipment show similar measurement results, although TELSS-3 seismic recording system is digital, and SGD-SEL engineering seismic recording station (Figure 1) is analog.

Figure 1. SGD-SEL engineering seismic recording station.

Seismic measurements at the blast furnace facility foundations were carried out by means of location spread of streamer (sounding locations). Triaxial geophones in the quantity of 8 pcs. were installed on the horizontal surface of foundation when using such method of geophysical measurements. During the warm season, seismic receivers were adhered to the surfaces with clay solutions and adhered by freezing at negative temperatures: in both cases, instruments were securely fixed and received a seismic wave. The following monitoring system was chosen for measurements: receiving point interval (RP) is 0.1–0.5 meters, near trace offset of source point (SP) from a receiving point is 0.1 meter, and far trace offset is 0.4 meters. Fluctuations in P-waves (primary waves) were excited by applying hammer blows in source points, and S wave (secondary wave) is excited by applying the second set of blows on the side face of foundation. The seismic recording station was operated in the signal accumulation mode - 8 blows at each sounding location. The signal sampling rate was selected to be minimal – 0.125 ms, the record length is 1,024 readings, and seismic data were presented in the SEG-Y format.

3. Wave field interpretation and processing procedure

AZON system of geophysical information processing was used (developed by A E Zudilina, Ural State Mining University, Certificate of State Registration of Computer Program No. 201317598) for digital processing of field data [6–10].

This processing system is based on the idea of three-dimensional seismic location. One of the elements of this system is the procedure of wave field pre-stack depth migration according to the system of azimuthograms with various combination ‘source-receiver’.

The physical justification for the possibility of segregation of the foundation bottom is the high frequency content of the analyzed wave field with the upper boundary of the degree of 2.500–3.000 Hz. This frequency range at the set speed of elastic waves provides a wavelength of about 1.2–1.5 meters. According to theoretical background, vertical resolution capability of the method is ¼ of the wavelength equal to 0.3–0.4 meters, i. e., the depth error of substructure of the foundations according to geophysical data is ± 0.3–0.4 m.

According to the elastic properties, the foundation concrete and the country rock are different, which makes it possible to separate the reflected (diffracted) wave from the bottom of foundation. The bottom of foundations is the source of both reflected and diffracted wave, and the foundation itself is a waveguide. In any case, the bottom half of the foundation must appear in the wave field as the negative phase of the reflected wave with a subvertical and downward directed orientation of directivity graph of excitation source.

A standard processing flow of individual sounding is generated for processing of the data of seismic measurements.

1. Input of shooting geometry for subsequent correction of radial component phases taking into account the approach direction of target reflected wave in a horizontal plane.

2. Oversampling of initial seismic records at 0.1 ms intervals. The use of this procedure is related to the necessity of resolution enhancement as well as assessment precision of the target reflection depths. This reconstitution ensures increase of Nyquist frequency from 4.000 to 5.000 Hz. The following stacking of eight sensors for each source point allows to expand the usable bandwidth by virtue of statistical effect.

3. Accounting of geometric spreading.

4. The high-pass filtering for the purpose of relatively low-frequency coherent-noise suppression. The cut-off frequency is 400–800 Hz depending on the specific acceptance and excitation conditions. The high noise level caused mainly by the metal parts of foundation requires rigid high-pass filtering with the cutoff frequency close to the upper boundary of the specified range. This may also lead to usable bandwidth reduction as well as occurrence of high-frequency ‘ringing effect’ on the records.

5. Deconvolution for the purpose of bandwidth expansion by increasing its upper boundary (within the range of up to 5.000 Hz).

6. Corrective filtering.

7. Recalculation of traces into the depth scale using the P-wave velocity.

8. Normalization of the trace average amplitude prior to summarization and determination of coherency.

9. Correction of phases of horizontal component traces. The phases change by 180 degrees or remain unchanged depending on the relative position of the excitation source and the receiving point for horizontal component traces (approach direction of the target reflected wave). A change of trace polarity including vertical components was observed in some cases due to rereflection from vertical flanges and units of construction installed in the foundation. Such traces were rejected or used in case of reverse polarity when calculating multifold composite traces upon condition of waveform retention during rereflection.

10. Calculation of multifold composite traces.

11. Calculation of coherence functions of multifold composite traces. This procedure was used for enhancement of validity of separation of the dedicated phases of reflection, since their amplitude is not always significantly higher than the amplitude of the coherent noise. Evaluation of coherence function is unbiassed, that is, in case of its absence in the current reflection interval (depth), its value is close to zero. Availability of target reflection is determined confident enough according to the sharp coherence improvement in almost all practices of this procedure. The peak value of coherency in the target range usually significantly exceeds the values in the remaining intervals, except for the first arrivals (muting was used for better displaying of graphic chart in the area of the first arrivals).

It should be noted that due to rereflection, the coherency of the first arrivals is often even lower than for the target reflecting boundary, which indicates a high efficiency of the procedure.

The minimum-phase deconvolution, converting the traces to zero phase and usually used for the purpose of more precise determination of the depth by the maximum of the multifold composite trace, was not used because of the shape (strongly distorted by rereflection) of the probe pulse recorded in the first arrivals.

For this reason, the depth to the target boundary (bottom of foundation) was determined according to the beginning of the negative phase of reflected multifold composite trace wave (Figure 2).

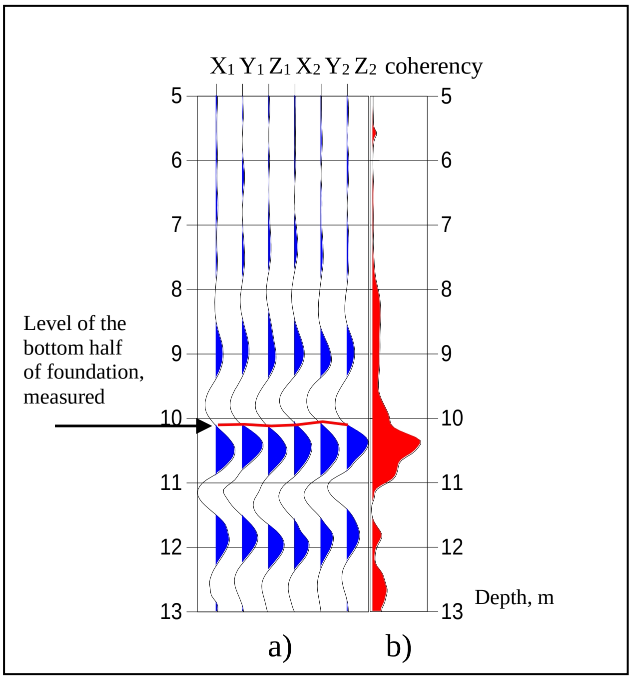

Figure 2. Example of wave field (a), coherence function (b) for determination of the foundation vertical dimensions.

The turnover of the coordinate system of the sensor axes by 45 degrees is connected with the necessity to obtain traces of horizontal components of approximately equal amplitude for each source

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point. This shall ensure the high noise resistance of depth migration. Also, if it is impossible to use depth migration, the use of component traces of consistent amplitudes with the selected orientation of sensitive axes allows to use the procedure of group coherency between multifold composite traces more efficiently.

4. Measurement results

Reproducibility of results of foundation bottom laying depth with actual depth was checked using engineering seismic recording systems by uncovering of foundation check pit-holes at the blast furnace complex facilities No. 7 of JSC EVRAZ NTMK. The measurement results are given in Table 1.

Table 1. Measurement results of foundation bottom laying depth using engineering seismic recording systems with actual depth at the blast furnace complex facilities No. 7 of JSC EVRAZ NTMK.

No.	Name of facility	Depth of foundation measured by means of seismic survey, N1, mm	Depth of foundation measured in check pit-hole, N2, mm	Maximum discrepancy, mm
1	Coke conveyor line. Kl-2 conveyor gallery	3.500–3.600	3.800	–300
2	Coke conveyor line. PS-3a transfer station	2.500–2.600	2.400	200
3	Stove block chimney	3.100–3.200	3.030	170
4	Stove block	3.200–3.300	3300	–100
5	Central unit of blast furnace	2.900–3.000	2.750	250
6	Casthouse No. 1	3.300–3.400	3.300	100
7	Cable tray system to the building of blast-furnace control panel	2.400–2.500	2.400	100
8	Dust collector with gas ducts Foundation of support system of axial cyclone	2.000–2.100	2.100	–100
9	Scrubber with droplet separator	9.800–10.000	9.500	500
10	Hoist room of dust collector with gas ducts	8.500–8.700	8.600	100
11	Bin trestle	5.100–5.300	5.500	–400

5. Conclusions

Taking into account a large amount of utility lines and continuous production process, the use of modern geophysical research methods is a very relevant and top requested method for determination of the depth of various types of foundations under the conditions of production metallurgical site.

The measurement accuracy of pile foundations and spread foundations equal to 0.5 meters was achieved by means of seismic techniques as a result of the measurements conducted at the metallurgical production facilities. This accuracy is achieved with the use of specific procedures of field data processing as well as using the idea of three-dimensional seismic location and statistical approach to interpretation of the results obtained.

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